# Suggestions for the Development of Design Criteria for Precision Deployment Mechanisms

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# The Prevailing Responsibilities of the Microdynamics Community

**1. To <u>clearly define</u> what (if any) "modes" of microdynamic response constitute "failure" modes of the structure.**

- What are the critical loads (i.e., disturbances) that the structure must sustain?
- What are the critical response modes (OR amplitudes) that must NOT be excited within the structure?

**2. To <u>clearly define</u> design/validation guidelines and criteria which preclude microdynamic failure.**

- We can't "analyze" the "art" out of design, but we can identify <u>deterministic</u> relationships that facilitate the <u>heuristic</u> design process.
- We should be able to establish REASONABLE and ADEQUATE criteria. (e.g., Microdynamic equivalents to "knock-down" factors commonly used in stability of imperfect members?)

**(Subject of this presentation)**

# Developing Design Guidelines and Criteria for Precision Deployment Mechanisms

- **Motivation:**
  - Pressure to reduce the cost of space vehicles has spawned **new** sub-disciplines of design like precision deployable structures.
  - Adequacy of any engineering design can only be defined relative to some accepted standards or criteria.
  - No such criteria currently exist for the design of precision deployment mechanisms.

- **Precedent:**
  - In the early 1960's, pressure to expand the capability of space vehicles simulated development of new sub-disciplines of design.
  - Uniform design criteria were developed jointly by NASA, industry, and academia and were published in 15 Design Criteria Monographs.
  - Since these fields were advancing substantially at the time, the monographs were "living documents" that have evolved over time

# The “Anatomy” of the NASA Design Criteria SP’s from the 1960’s

**The Background and Motivation:** Filled gaps of nowledge and a need for uniformity AND onformity in the design of flight vehicle systems.

**The Classification:** “Design Criteria” is a nisnomer. “Design Guidelines” is more accurate.

**The Scope:** One specific response phenomenon. e.g., “Buckling of Thin-Walled Circular Cylinders” nstead of “Design of Circular Cylinders”).

**Authorship:** Broad participation from academia, ndustry, and NASA. (No single author or editor.)

**Theme:** What we know. What we think we know. What we think. Supported by equations, data, umbers, AND the caveat that things might change.

**References:** Extensive. The SP’s basically ummarized and applied the current literature.

NASA SPACE VEHICLE DESIGN CRITERIA (STRUCTURES)

NASA SP-8007

BUCKLING OF THIN-WALLED CIRCULAR CYLINDERS

SEPTEMBER 1965
Revised
AUGUST 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# Suggestion for a New NASA Design Criteria Monograph for Precision Deployment Mechanisms

**Scope:** <u>Focus on one specific response</u> <u>henomenon: hysteresis</u>. Why hysteresis? It is the ne quantifiable response phenomenon within eployment mechanisms that should be linkable to pecific "failure modes" within a deployable tructure (e.g., mirolurches, thermal "pops", etc.)

**Theme:** *"What we know. What we think we know. Vhat we think."* Present methods for analyzing and xperimentally quantifying hysteretic response. Present design principles and guidelines for reducing ysteresis. <u>Facilitate a merger between ptomechanical and aerospace-mechanical design hilosophies.</u>

**Participation:** <u>Representatives from the nicrodynamics research community and both the ptomechanical and deployment-mechanism-design ommunities</u>. (e.g., NASA LaRC, JPL, CU, Raytheon, AEC Able, SPIE, etc., etc., etc.)

**Funding Support:** ??????????

NASA SP-XXXX

**Hysteresis in High-Precision Deployment Mechanisms for Optical Instrument Structures**

National Aeronautics and
Space Administration

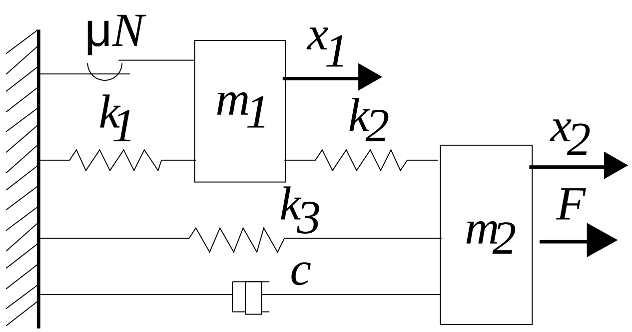
June 2000

# Suggested Contents of a Precision Deployment Mechanism Design Criteria Monograph

- **Introduction**
  - Linkage between component hysteresis and structural microdynamic failure modes.
- **State of the Art**
  - Deployment mechanism design principles
  - Optomechanical mechanism design principles
- **Criteria**
  - Definition of hysteretic-response criteria
- **Recommended Practices**
  - Analysis methods for facilitating design
  - Test methods for qualifying design

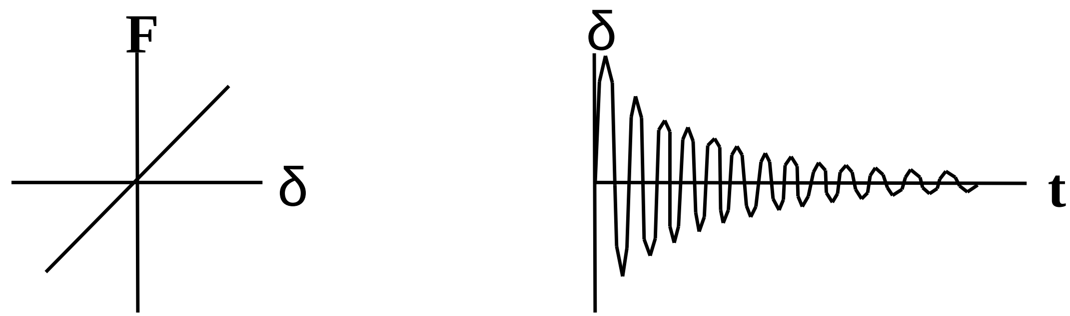
# Introduction

# Simplified Load-Transfer Model Illustrates Relationship Between Structural Hysteresis and Possible "Mode 1" Microdynamic Failure (Gross Slippage)

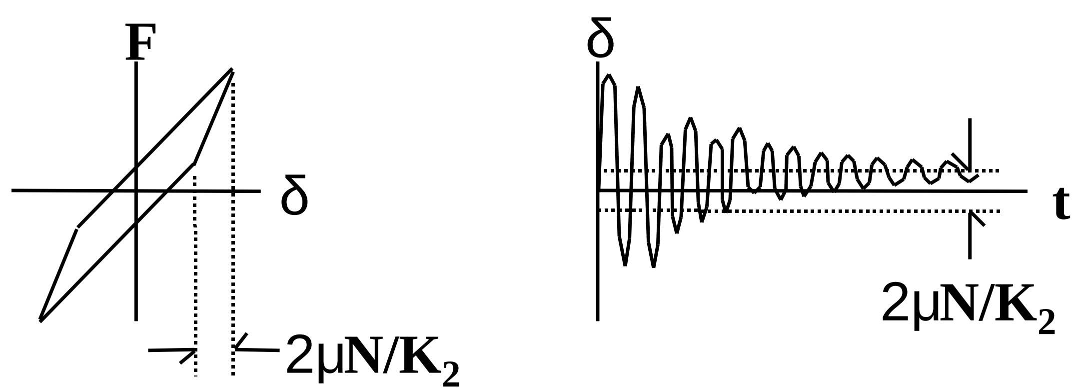



Model Parameters

## Linear Response Below Stick-Slip Threshold



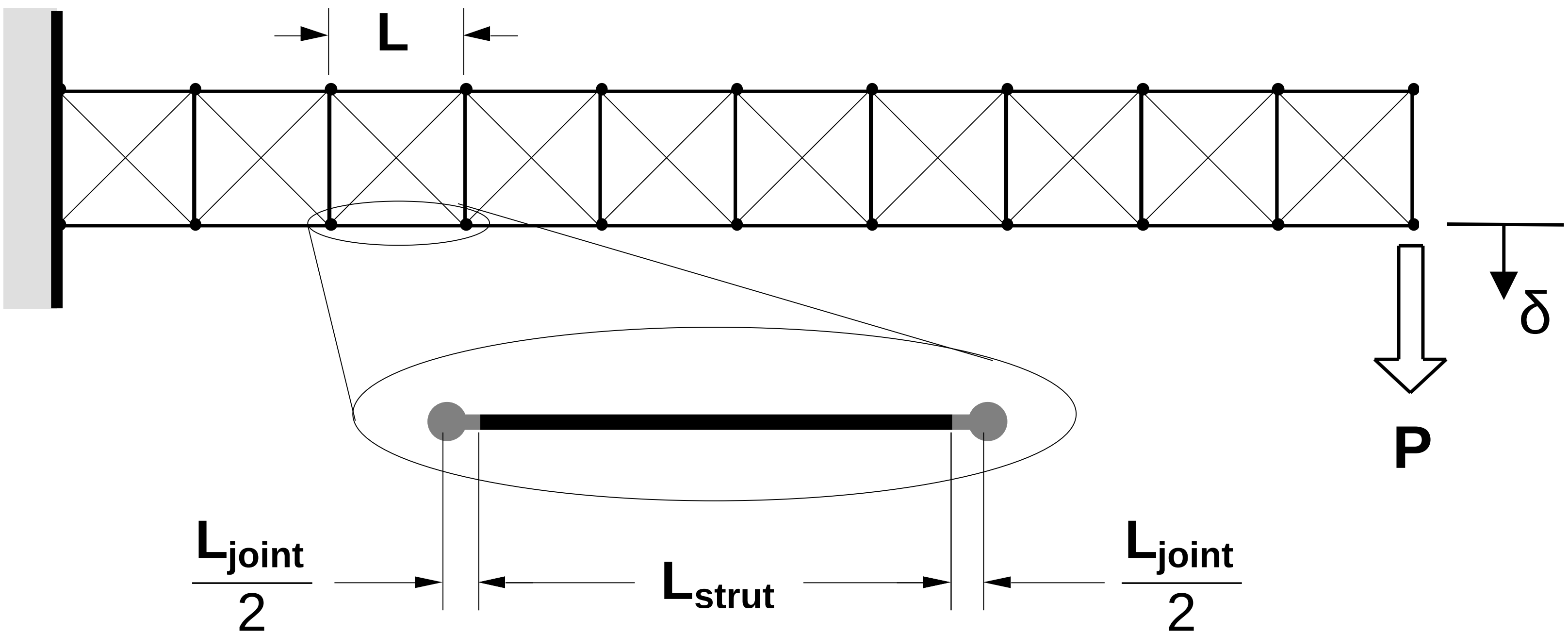

## Nonlinear Response Above Stick-Slip Threshold




Hysteresis

Microlurch

# Mitigating “Mode 1” Failure Involves Minimizing Structural Hysteresis ($\varepsilon_{total}$) By Tailoring Component Stiffness and Hysteresis (      )




**Linear response:**

$$= \frac{P(nL)^3}{3(EI)_{eff}} = \frac{Pn^3}{3}\left(\frac{L_{joint}}{(EA)_{joint}} + \frac{L_{strut}}{(EA)_{strut}}\right)$$

**Total (linear + hysteretic) response:**

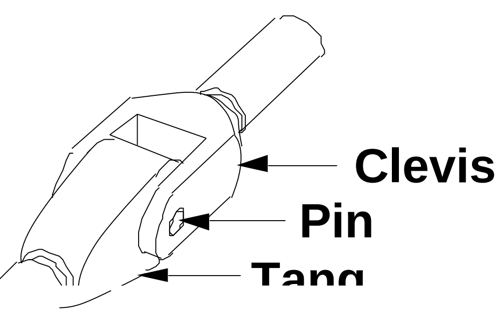
**For any determinant truss with identical struts and joints, structural hysteresis i**

$$\varepsilon_{total} = —$$

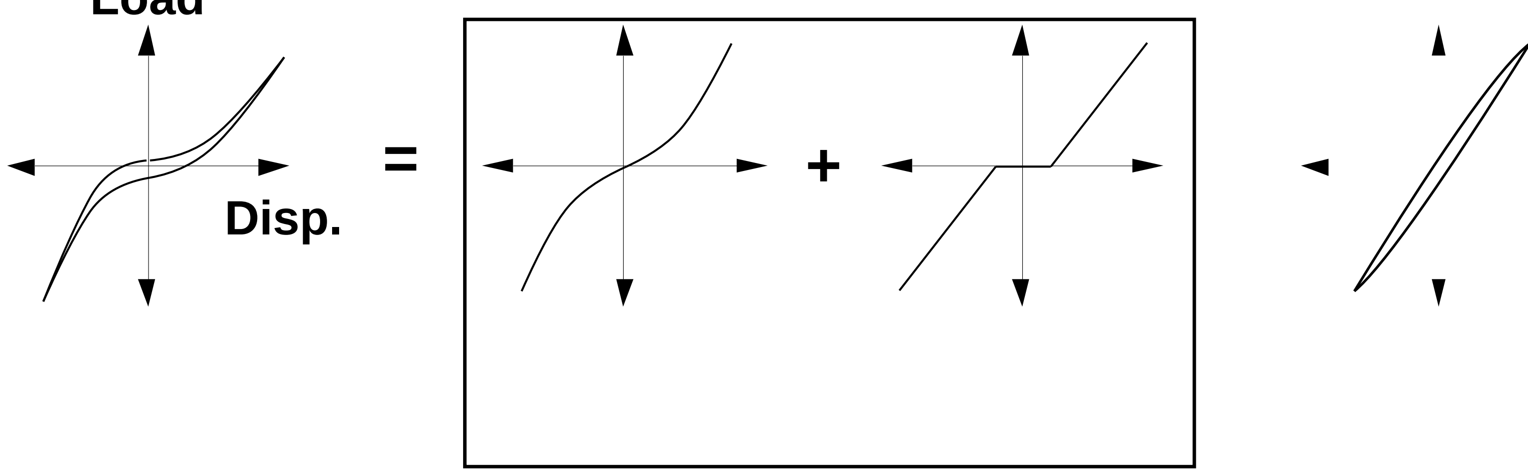
# State of The Art

# State of the Art in Deployment Mechanism Design

- **The <u>true</u> state of the art in high-precision deployment mechanisms is difficult to establish due to the possible classified experience.**
- **The unclassified literature indicates that the majority of applications are sub-optical-precision (i.e., solar arrays and RF antennas).**
  – Hachkowski, M. R., and Peterson, L. D.., A Comparative History of the Precision of Deployable Spacecraft Structures, University of Colorado publication CU-CAS-95-22, December, 1995.
- **Emphasis tends to be on simplicity (i.e., low part count), low mass, high stiffness. <u>Nonlinearities reduced PRIMARILY through preload</u>.**




**<u>Typical Hinge Joint</u>**




**<u>Reduced or eliminated by preload</u>**

# State of the Art in Optomechanical Design

- **Numerous publications present design principles for optical-precision mechanisms such as positioning devices and kinematic mounts.**
  - Jacobs, D. H., Fundamentals of Optical Engineering, McGraw-Hill Book Co., 1943.
  - Vukobratovich, Daniel, "Principles of Optomechanical Design," in Applied Optics and Optical Engineering, Vol. 11, R. R. Shannon and J. C. Wyant, ed, Academic Press, 1992.

- **These principles are presented implicitly, through the discussion of specific examples. (Therefore, it is not obvious how these principles might be applied to the design of deployment mechanisms.)**

- **Emphasis tends to be on the use of deterministic geometries (e.g., kinematic mounts) and non-conforming interfaces (e.g., spherical contacts) as opposed to stiffness/strength concerns.**

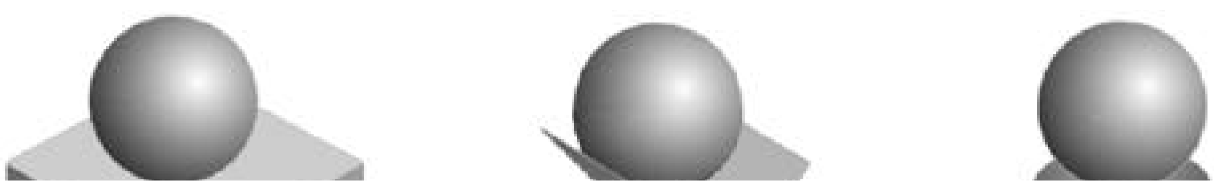


**Figure from Vukobratovich's reference depicting "optically quiet" 1-, 2-, and 3-DOF constraints**

# Criteria

# A <u>Useful</u> Criterion on Deployment Mechanism Performance is One Derived from a Specific Microdynamic Failure Mode and Relatable to Specific Design Principles. . .

**Recommended practices derived from optomechanical design principles**

**Minimize joint hysteresis**

$$\varepsilon_{total} = \frac{\varepsilon_{joint}}{1 + \dfrac{\left(\dfrac{EA}{L}\right)_{joint}}{\left(\dfrac{EA}{L}\right)_{strut}}}$$

**Maximize joint stiffness**

**Recommended practices derived from deployment mechanism design principles**

# Recommended Practices

***Just "spice up" our existing deployment mechanism design practices with a "dash "of optomechanical design principles. . .***

# In a Sense, Dr. Hachkowski Performed Detailed Hysteretic-Response Analyses of Deployment Mechanisms, and out "fell" the Optomechanical Design Principles!

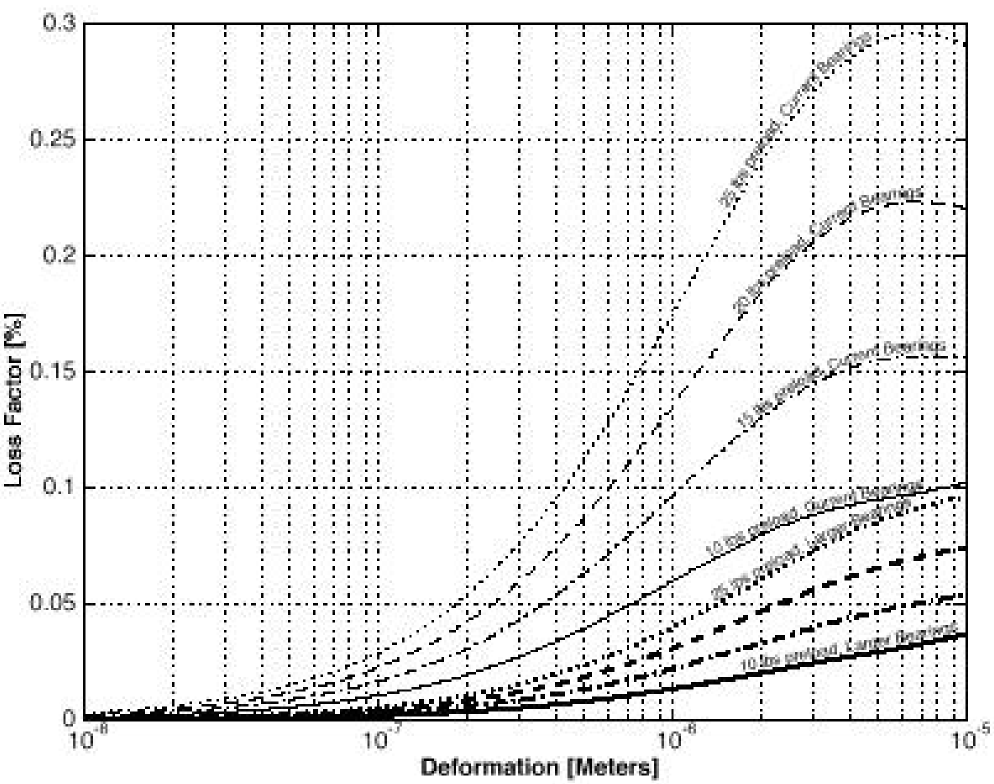
– Hachkowski, M. Roman: "Reduction of Hysteresis in the Load-Displacement Response of Precision Deployment Mechanisms Through Load Path Management," University of Colorado, 1998

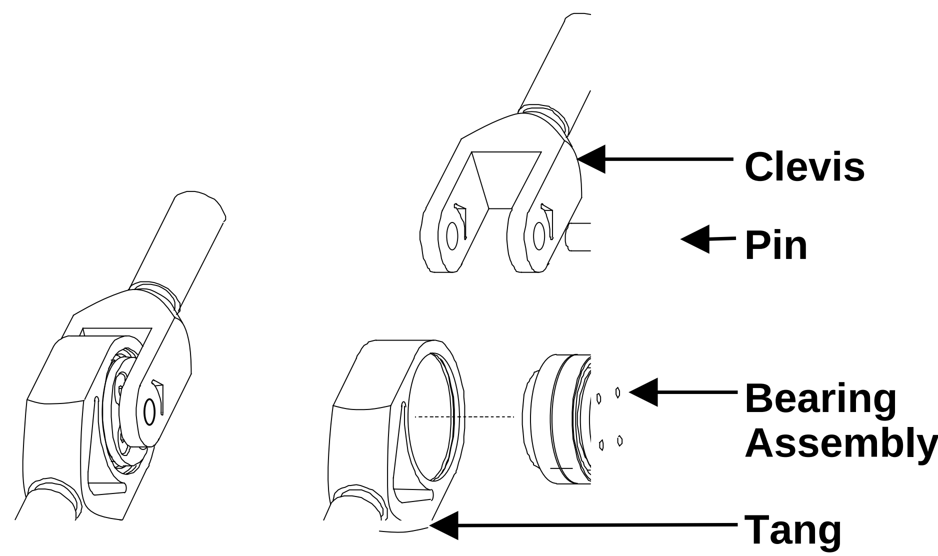
- **Objectives:**
  - Establish precedents for modeling interface contact mechanics and their effects on stiffness and hysteresis in precision deployment mechanisms.
  - Derive design principles for minimizing hysteresis and maximizing stiffness in precision deployment mechanisms.

- **Principal Contributions:**
  - New theoretical model of rolling element mechanics including interface stiffness and nonlinear friction microslip.
  - "Load-Path Management" design methodology, which is relatable to optomechanical design principles.

# Hachkowski’s Detailed Modeling of Contact Mechanics Within a Precision Hinge Led to Substantial Design Insight

- **In general, hysteretic “loss factor” varies with response amplitude:**
  - collapsing to material loss factor at low amplitude (Mode 3/4 failure regime?)
  - reaching a peak at a moderate amplitude (Mode 1/2 failure regime?)
- **For this specific joint design:**
  - larger bearings DECREASE loss factor.
  - larger preloads INCREASE loss factor.

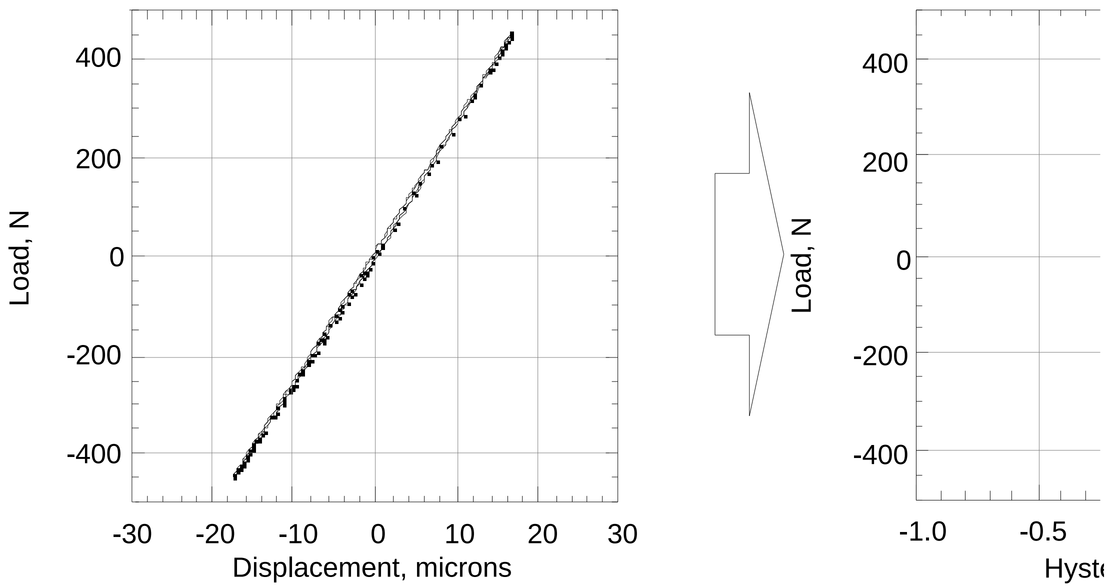


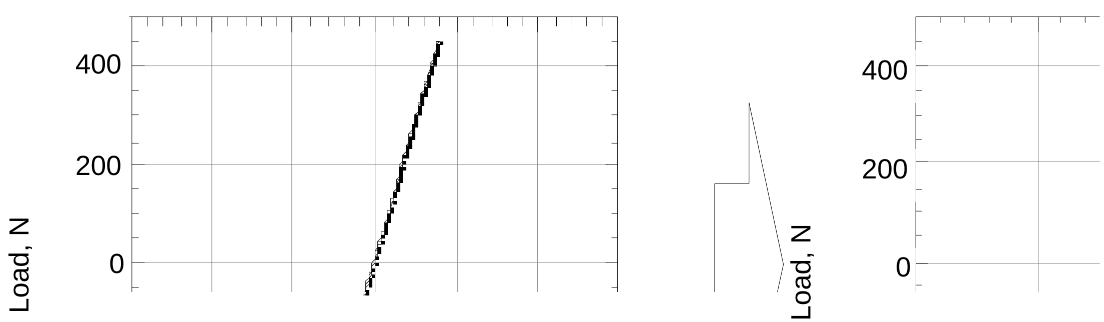
# Composite Version of Hinge Joint Developed to Exhibit Higher Stiffness (and Lower CTE) Than Prototype Aluminum Hinge

- Same internal (i.e., bearing and press-fit pin) design
- Thicker, higher-modulus composite tang and clevis

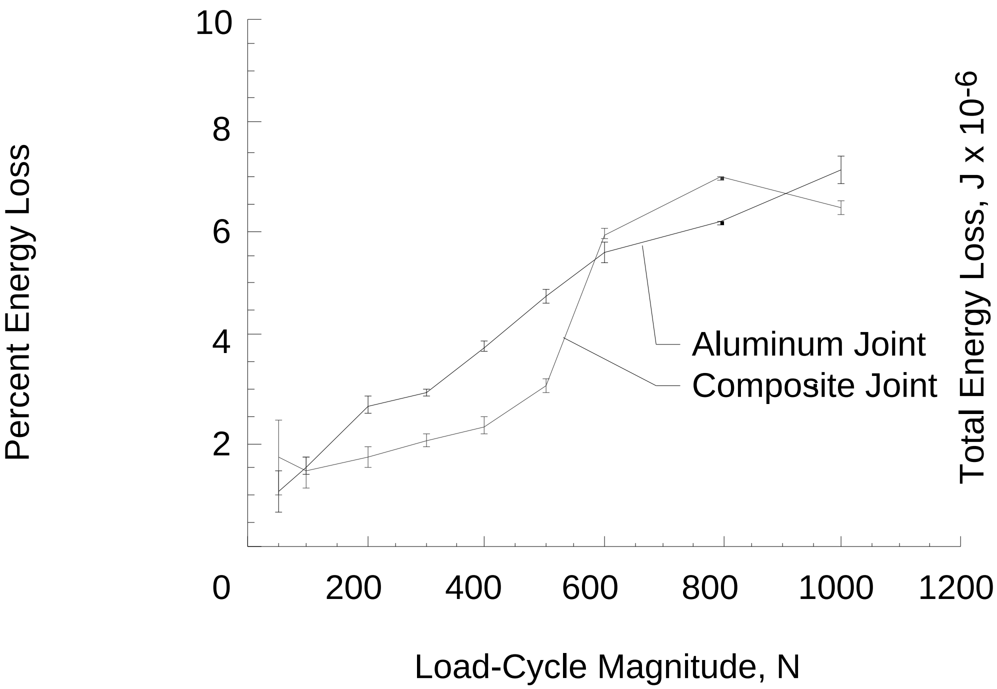
**<u>Aluminum Hinge Data</u>**
**(Gage Length = 3.5”)**

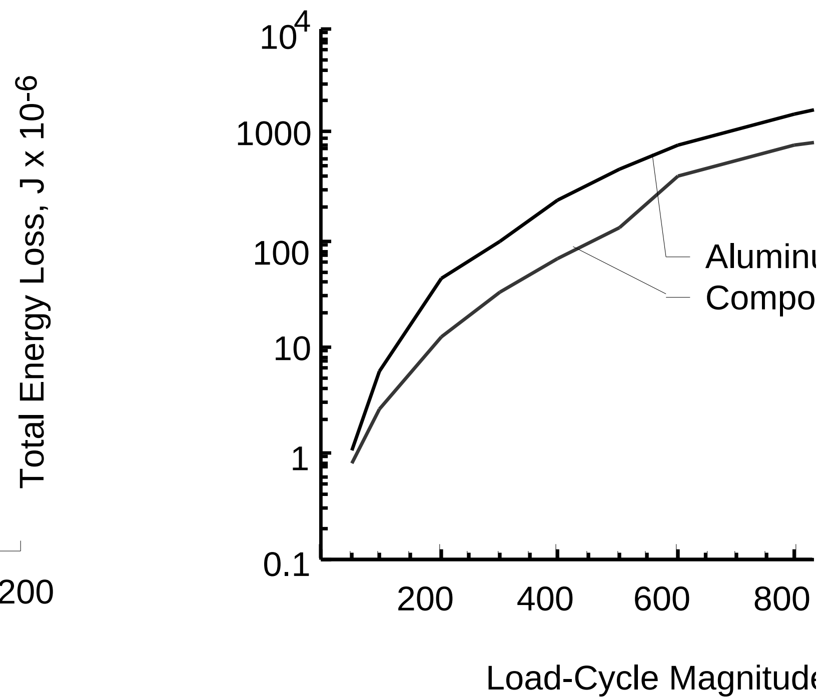



**<u>Composite Hinge Data</u>**
**(Gage Length = 2.75”)**



# Results Indicate that Their Can be a Synergistic Effect on Hysteresis of Increasing the Joint Stiffness



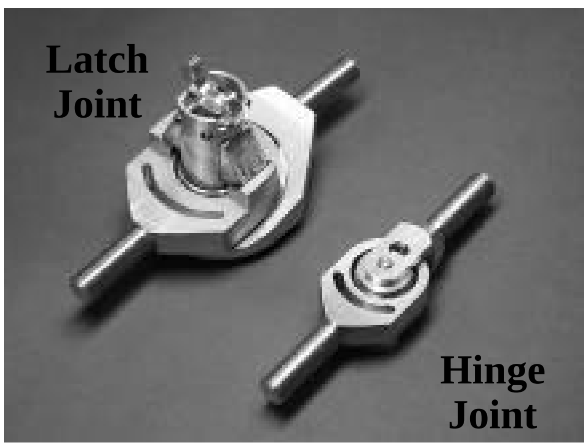



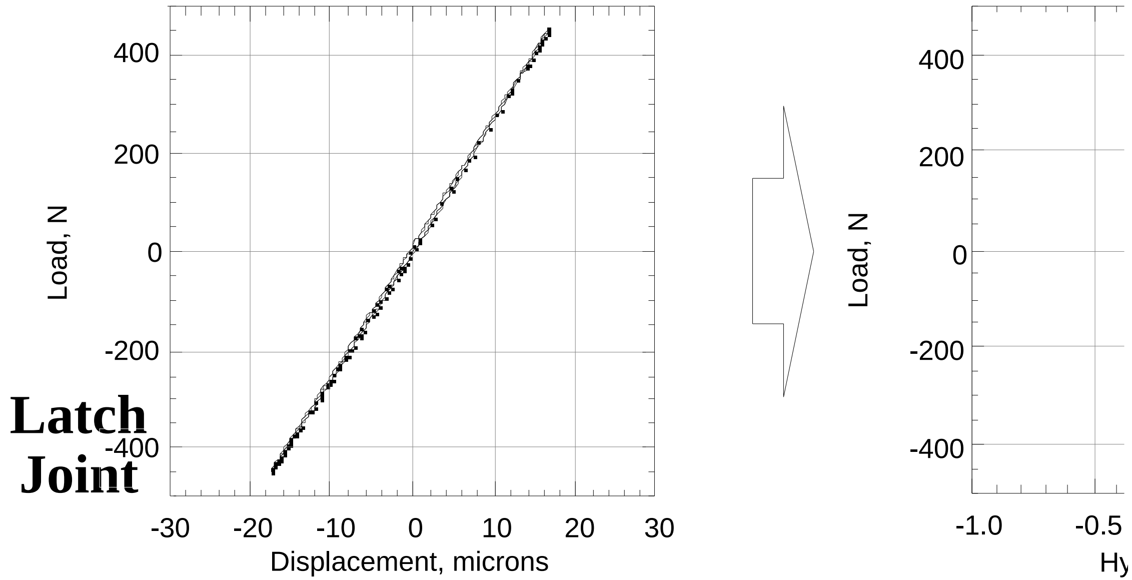

***Higher loss factors in the aluminum joint are likely due to local elastic deformation of the pin and slippage of the pin interfaces.***

# Similar Results From a Precision Latch Indicate that Achieving <u>Extremely Low Hysteresis</u> Might Require Sacrifice to Stiffness

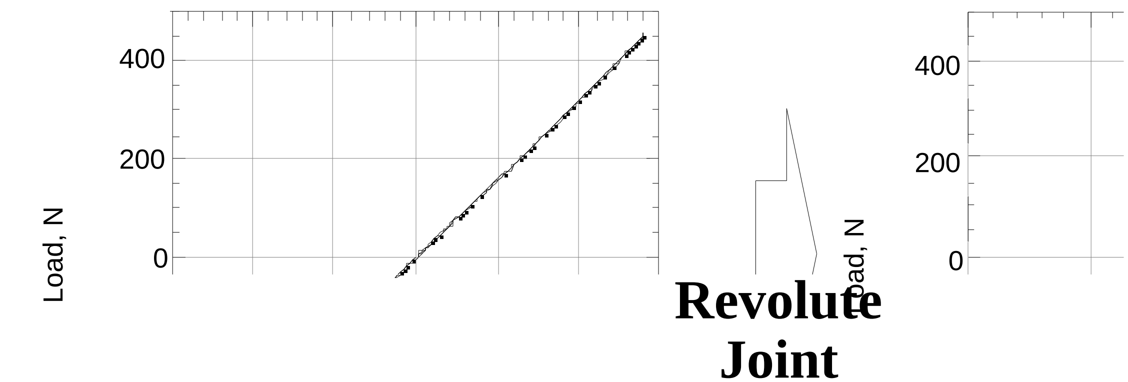
- Larger-diameter bearing than the prototype hinge
- Larger-diameter press-fit assembly pin than the prototype hinge

**<u>Hinge Joint Data</u>**
**(Gage Length = 3.5”)**




**<u>Latch Joint Data</u>**
**(Gage Length = 3.8”)**



# Summary

*Adequacy of any engineering design can only be defined relative to some accepted standards or criteria.*

*Until we develop such criteria for precision deployment mechanisms, the issue of microdynamics will remain controversial and difficult for missions to deal with.*